

Photon-tagged jet measurements in Pb+Pb collisions at $\sqrt{s_{NN}}=5.5$ TeV with the CMS detector

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Abstract. Presented are the results of a detailed study for a complete simulation of the CMS detectors at the LHC in view of the expected modification of jet fragmentation functions in central Pb+Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV compared to the vacuum (p+p) case. The study is based on γ -jet events, using the correlation between isolated high-transverse energy ($E_T > 70$ GeV) photons and fully reconstructed jets, based on the information provided by the CMS calorimeters and silicon tracker.

One of the key results from the study of high-energy nuclear (Au+Au and Cu+Cu, $\sqrt{s_{NN}} = 200$ GeV) collisions at the Relativistic Heavy-Ion Collider (RHIC) is the observation of the strong suppression of leading hadron yields at transverse momenta $p_T \gtrsim 5$ GeV/c, compared to expectations based on p+p and d+A collisions at the same collision energies [1]. This observation is called “jet-quenching” and commonly explained by assuming that the hard partons lose a large fraction of their initial energy due to interactions with the surrounding strongly-interacting medium. The extreme magnitude of the suppression (up to factor 5) makes the interpretation of the inclusive measurement difficult, as the observed remaining yield of high- p_T hadrons is likely to be dominated by emission from the surface of the collision region [2, 3], and therefore allows a variety of qualitative different models to describe the data quantitatively equally well [4]. The collisional and radiative energy loss of the hard partons should lead to characteristic changes in the jet fragmentation pattern [5], but a direct measurement of jets in central nucleus–nucleus collisions is not feasible at RHIC energies. Pb+Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV at the Large Hadron Collider (LHC) will allow one to study the jet quenching phenomenon in more detail. Due to the very large cross-sections for hard parton-parton scattering, a significant fraction of the produced jets will have enough transverse energy to individually stick out of the underlying heavy-ion background. Therefore identified jets can be used to characterize the initial partons event-by-event. The CMS detector will collect large event samples for the study of such rare probes, thanks to the large geometrical coverage of the electromagnetic (ECAL) and hadronic (HCAL) calorimeters ($|\eta| < 3$) and of the charged-particle tracking ($|\eta| < 2.5$), both fully covering the azimuthal angle. Equally important is the capacity of its triggering and data acquisition systems to inspect every Pb+Pb collision, giving priority to the storage of rare events [6]. The expected statistical significance of the event

samples, will allow us to study in detail even the γ -jet channel. This channel is particularly interesting since the direct photon is not affected by the presence of the medium, and thus can be used as an unambiguous tag of the away-side parton, contrary to the case of back-to-back di-jets [7]. The main idea of the analysis is to use the transverse energy of the direct photon (E_T^γ) as an estimate of the E_T^{jet} of the away-side jet, and thus to avoid the precise measurement of the absolute E_T^{jet} . Hence, the jet fragmentation function $1/N_{\text{jets}} dN/dz$, the normalized distribution of fractional particle transverse momenta relative to E_T^{jet} , can be approximated by using $z = p_T/E_T^\gamma$ for particles associated with the jet (Fig. 1). Of course, to be useful as a tag, the direct photon should emerge back-to-back with respect to the away-side jet. This topology is disturbed by initial and final state radiation. Therefore, a cut on the opening angle between the photon and the emerging jet is applied.

In this report, we present the jet fragmentation functions for photon-tagged jet events with $E_T^\gamma > 70$ GeV, reconstructed from the simulated response of the CMS detector systems for central Pb+Pb collisions. The studies are performed for two extreme scenarios, where PYQUEN [8] and PYTHIA [9] are used to generate the QCD signal and background channels with and without jet quenching, respectively. In both scenarios, HYDJET [10] is used to model the underlying heavy-ion event. For this study, the 10% most central Pb+Pb collisions are selected by the impact parameter of the lead nuclei, yielding an average mid-pseudorapidity density of about 2400 (2200) charged particles in the quenched (unquenched) case. In total, 4000 γ -jet events in the CMS acceptance for $E_T^\gamma > 70$ GeV and $|\eta^\gamma| < 2$ with $\Delta\phi(\gamma, \text{jet}) > 172^\circ$ and about 40000 (125000) QCD background events for the quenched (unquenched) case are simulated. This corresponds to the expected yields for one running year of Pb+Pb data taking with an integrated luminosity of 0.5 nb^{-1} . More details can be found in Ref. [11].

Jet reconstruction using the ECAL and HCAL calorimeters is performed by an iterative cone algorithm with a cone size of $R = 0.5$ in the η - ϕ plane modified to subtract the underlying soft background on an event-by-event basis [6]. Tracks are reconstructed using seeding from one hit on each of the three layers of the silicon pixel detector (resulting in a geometrical acceptance of 80%), with an extension of the standard tracking algorithm used for p+p [6]. In this high-multiplicity environment, an algorithmic tracking efficiency of about 70% is achieved near midrapidity, for $p_T > 1 \text{ GeV}/c$, with a few percent fake track rate. High- E_T isolated photon reconstruction, newly developed for this analysis, proceeds in three steps. At first, photon candidates are obtained by reconstructing clusters of hits measured in the ECAL using the Island clustering algorithm [12]. Second, for each photon candidate, the information provided by several shape variables in the ECAL associated with the candidate is examined. Third, together with the information from the HCAL and the tracker, we determine if a given photon candidate is an isolated photon. The combined information of these variables forms a three-dimensional space, in which optimal rectangular cuts are obtained (Fig. 2). The working point for this analysis is set to 60% signal efficiency, leading to a background rejection of about 96.5%, and to a signal-to-background ratio of

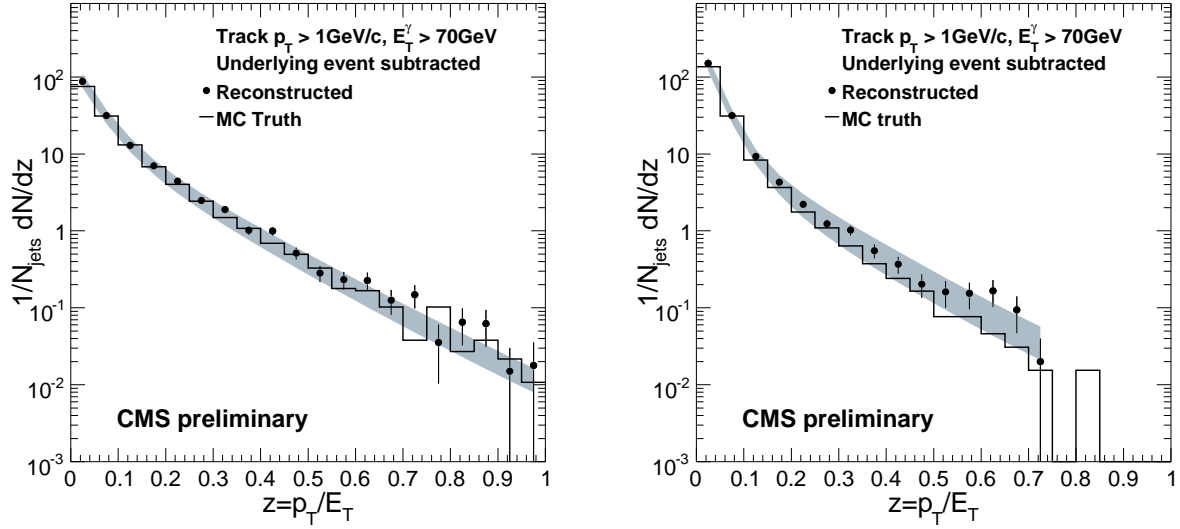


Figure 1. Reconstructed fragmentation function in Pb+Pb collisions (symbols) compared to MC truth (line) for the unquenched (left) and quenched (right) scenario. The estimated systematic error of the measurement is represented as the shaded band.

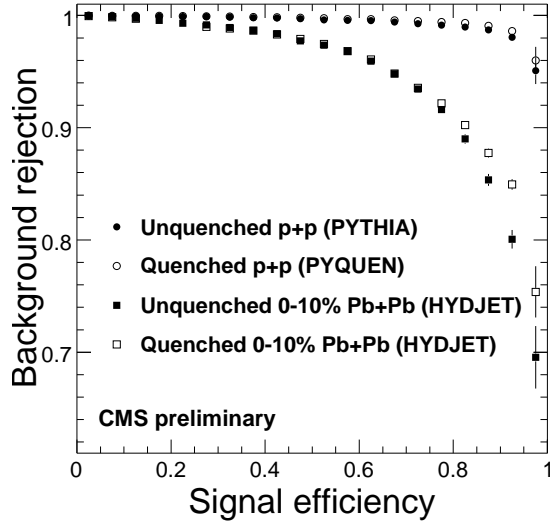


Figure 2. Background rejection versus signal efficiency for the identification of isolated photons in different systems. The coefficients and cuts are obtained for the corresponding unquenched sample and applied to the quenched one.

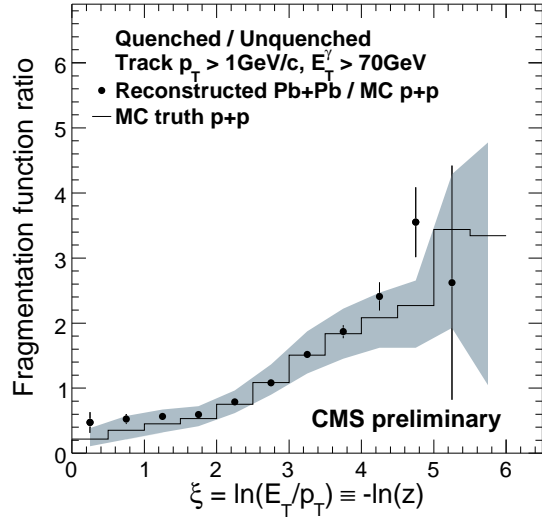


Figure 3. Ratio of reconstructed (symbols) and MC truth (line) quenched fragmentation function over unquenched MC truth. The estimated systematic error of the measurement is represented as the shaded band.

4.5 for 0 – 10% central quenched Pb+Pb. On average, for $E_T^\gamma > 70 \text{ GeV}$, the transverse energy resolution for isolated photons is about 4.5%, and the spatial resolution in η and ϕ is better than 0.005.

To construct the fragmentation function, reconstructed isolated photons are

selected and correlated with reconstructed back-to-back calorimeter jets. An isolated photon with $E_T^{\text{jet}} > 70$ GeV and $|\eta^\gamma| < 2$ is associated with the highest E_T^{jet} calorimeter jet in the event provided $\Delta\phi(\gamma, \text{jet}) > 172^\circ$ is fulfilled. Since we obtain the charged particle information from the tracker, the away-side jet ($R = 0.5$) associated with the photon needs to be contained in the tracker acceptance of $|\eta| < 2.5$. Therefore, we require the reconstructed jet axis to be within $|\eta| < 2.0$ to avoid edge effects at the limit of the tracker acceptance. A minimum E_T^{jet} cutoff of 30 GeV is applied in order to ensure that the reconstructed calorimeter jet corresponds to the away-side parton. For the selected photon-jet pairs, reconstructed charged particles that lie within the $R = 0.5$ cone size around the reconstructed jet axis are selected. The raw fragmentation function is constructed correlating the transverse energy of the photon, as a measure of the parton transverse energy, with the reconstructed transverse momentum of the tracks in the cone. The underlying event contribution is estimated by using the momentum distributions of tracks within a $R = 0.5$ radius perpendicular in the ϕ to the reconstructed jet axis and subtracted from the raw distribution. The reconstructed fragmentation functions are overlaid with the MC truth determined at generator level using the true parton E_T and direction for the selection of particles (Fig. 1). Essentially four main sources are found to contribute to the systematic differences between the reconstructed and true fragmentation functions and added in quadrature to obtain the total systematic error:

- (i) QCD jet fragmentation products misidentified as isolated photons ($\sim 15\%$).
- (ii) Association of a wrong/fake jet on the away-side of the isolated photon ($\sim 10\%$).
- (iii) Uncertainties in the charged particle reconstruction efficiency correction ($\sim 10\%$).
- (iv) Biases due to lower jet reconstruction efficiency at lower jet E_T ($\sim 30\%$).

The overall capability to measure the medium-induced modification of jet fragmentation functions in the γ jet channel can be illustrated by comparing the fully reconstructed quenched fragmentation function to the unquenched MC truth distribution (Fig. 3). The change in the fragmentation function between the unquenched and quenched case provides the scale against which the estimated uncertainties should be compared.

In summary, we have shown that γ -jet events can be used to study quantitatively the dependence of high- p_T fragmentation on the medium. For a data set corresponding to one nominal year of CMS Pb+Pb running, the expected statistical and systematic uncertainties should be small enough that the measurements will be sensitive to the foreseeable changes in the fragmentation functions relative to parton fragmentation in vacuum.

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